2020 STRATEGIC PLAN

SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES

GEORGIA INSTITUTE OF TECHNOLOGY

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GEOSCIENCES IN THE 21ST CENTURY

As we enter the third decade of the 21st century, advances in the geosciences (defined broadly to include the study of the solid Earth, ocean, atmosphere and planetary bodies) are occurring at a dizzying pace, fueled by advances in measurement technologies, an abundance of data and new analytical techniques, and advances in computing power. Fleets of tiny robots swarm the ocean, monitoring the uptake of carbon dioxide from the atmosphere. High throughput sequencing of environmental DNA provides insight into the enormous diversity of life from high reaches of the Earth's atmosphere to the depths of the Earth's crust. Machine learning is advancing our ability to predict changes in climate. Electromagnetic pulses are being used to probe fluid reservoirs on the seafloor. Georgia Tech researchers in the School of Earth and Atmospheric Sciences (EAS) are using these tools and others to drive fundamental discoveries in the geosciences.

Our knowledge of other planets and planetary bodies in our solar system has been fed in recent years by a flood of new data from successful missions to Mercury all the way out to Pluto and beyond. Large international efforts to explore the outer solar system are expected to multiply in the coming decades, and there is the real possibility of additional missions to Mars, possibly including humans on longer time horizons. These programs will include life detection and sample return missions, and in the coming decades can help us to answer the question "are we alone in the universe". This will require expertise merging planetary science, ocean science, ice physics, and geomicrobiology with the ability to design and engineer spacecraft instrumentation with the capacity to detect life, past or present. This interest in life on other planets is intimately coupled with renewed efforts to understand the interaction of life and the environment on early Earth.

The geosciences also address more immediate concerns about the influences of a growing human population on the Earth and its environment. In its 2020 Global Risks Report, the World Economic Forum identified Environmental Risks, most with direct links to Earth and Atmospheric Sciences, as the most likely and impactful challenges that humanity faces. The human impact on climate is now incontrovertible, and the impacts of rising greenhouse gas concentrations on weather events, sea level, and ecosystems on land and in the ocean will continue to emerge in the decades to come. Pressure on finite water, mineral, and energy resources will continue to increase to meet mounting population needs, and provide for better living standards for the most at- risk citizens globally. Natural hazards, such as earthquakes and tsunamis, will have greater impact on more populated and urbanized environments. Geoscientists will play a critical role in reaching the Sustainable Development Goals set by the United Nations. Meeting these objectives will require advances in scientific understanding related to climate, water, geohazards, energy, and mineral resources. Scientists with access to this expertise must become fluent in the dissemination of this knowledge to those working to implement practical solutions.

There is a strong demand for a diverse geoscience workforce. Experts with undergraduate and graduate degrees in the geosciences are needed, with a projected 11% growth in geoscience jobs over the next decade. According to the American Geosciences Institute's latest assessment of the geoscience workforce, 48% of the workforce is likely to retire in the next decade (AGI 2018). The AGI report highlights the need for more quantitatively educated geoscientists who have gained real-world experience during their degree programs through internships and other experiences outside of academia. The report also highlights the fact that, among STEM fields, the geosciences stand out for the lack of racial and ethnic diversity. In 2016, only 2% of geoscience bachelor's degrees in the U.S. were awarded to African Americans and 9% to Hispanic students (AGI Status of the Geoscience Workforce, 2018). In 2016, only 6% of geoscience Ph.D.s were awarded to under-represented minorities (5% Hispanic/Latinx and 1% Black/African American) and there is no evidence of significant progress on this front in 40 years (Bernard and Cooperdock, *Nature Geosciences*, 2018). Unsurprisingly, these low numbers are reflected in the composition of the tenured/tenure track faculty. If the geosciences are to effectively tap the global talent pool, and if geoscientists are to fully participate in the solutions to global challenges, it is imperative that the demographics of the field better reflect society at large.

MISSION OF THE SCHOOL OF EARTH AND ATMOSPHERIC SCIENCE

- Produce breakthrough discoveries through research in Earth, atmospheric, ocean, and planetary sciences as well as interdisciplinary research involving the Earth system and the environment.
- Provide vibrant and inclusive learning experiences and environments that prepare students to pioneer the advancement of knowledge in the Earth, atmospheric, ocean, and planetary sciences and become the future leaders of academia, government, and industry.
- Effectively engage with the public both locally and globally to apply our scientific knowledge to inform public policy, resource management, and environmental stewardship.

VISION FOR THE SCHOOL OF EARTH AND ATMOSPHERIC SCIENCES

The vision that follows emerges from a detailed survey of the faculty in the School in January 2020. Twenty of the 22 faculty with primary, non-administrative appointments in the school provided input. Input was also solicited from faculty with secondary appointments in the School, postdoctoral fellows, and graduate students. We also relied on prior surveys of undergraduate alumni of the program. The strengths of our program were identified, along with untapped opportunities and areas for improvement. This vision builds on the existing strengths, and envisions what the School could become in the next decade.

EDUCATION

We will educate the next generation of scientific leaders in Earth, atmospheric, ocean, and planetary sciences.

Our undergraduate program provides strong preparation for graduate school in the Earth sciences and related disciplines and for scientific and technical careers in private industry and government. The students have access to rigorous courses that allow them to gain a strong grasp of fundamental scientific concepts and to develop problem solving and communication skills. Students have high-quality interactions with faculty given the low student/faculty ratio. Many of our undergraduate students engage in opportunities for research with top scientists. Our graduate program provides exciting and cutting-edge research opportunities under the mentorship of a uniformly strong, research-active faculty. Our coursework and examination requirements are flexible and accommodate the diversity of research areas covered within the department. We envision preparing more of our Ph.D. students to compete for top faculty positions, and careers in research and industry. They will have gained a mastery of their subject area, and a breadth of knowledge in the field. They will have developed the ability to create and follow through on their own novel research ideas, publish, and communicate them clearly.

We will educate the next generation of scientifically informed leaders in Industry, Government, and Non-governmental organizations.

Our students (both undergraduate and graduate) are increasingly setting their career goals outside of academic and government research careers. These students realize how many of the pressing issues of our time require an understanding of the Earth and its environment, and they desire to apply this knowledge more directly to societally relevant problems. They seek broader training in areas such as policy, media, and data analytics. We envision that we will provide coursework, degree programs, and guidance that will set these students on a path to success in a variety of career paths.

We will play a leading role in expanding the demographic diversity of the workforce in geosciences.

While the numbers have been low, the School has educated undergraduate students, graduate students, and post-docs from under-represented minority groups in percentages that exceed the national mean. In the 2019-2020 academic year, Black/African American students comprised 6% of EAS undergraduate majors (vs. national mean of 2%) and 5.7% of Ph.D. students (vs. national mean of 1%). Georgia Tech and the School of EAS have a unique opportunity to take a leadership role in expanding the diversity of the geoscience workforce given the reputation of the Institution and its location in the city of Atlanta. A particular emphasis on educating Black/African-American and Hispanic/Latinx scientists is warranted given the demographics of the city and state. However, we will strive to meet the needs of students of all backgrounds, and provide an inclusive environment considering all facets of diversity.

RESEARCH

We will lead in innovative research that produces advances in the fundamental understanding of the Earth (including the solid Earth, ocean, atmosphere, and near space environment) and other planets.

The School has an exceptionally strong, research-active faculty. Research achievements regularly result in high impact publications, funding success, and international recognition for EAS researchers and their teams. Two main foci for research exist in the school: The first thrust includes research in areas that support the better management of human interactions with our planet (e.g. natural hazards, landscape and coastal change, climate and environmental change, air and water quality). The second main emphasis is on science that will lead to fundamental advances in our understanding of the co-evolution of life and the environment on Earth, and the possibility of life-sustaining environments in our solar system and beyond. We anticipate maintaining and building strength in these areas, which are expected to grow in their relevance and funding base over the next decade. Historically, EAS has been able to keep its research program at the cutting edge by being exceptionally nimble, taking advantage of emerging opportunities quickly as they arise. Although these opportunities are not always clear until they present themselves, we envision that we will continue our broad outlook when considering both expansion and replacement faculty hires.

In light of our place at a premier technological university, our research will remain firmly grounded in the core sciences of physics, chemistry, and biology and will take advantage of cutting-edge technology, computing, and data analysis techniques.

A “tech” focus to research in EAS drives excellence by leveraging the strengths and resources of the institution as a whole and provides incentives for cross-school and cross-college research collaborations.

COMMUNITY AND SYNERGY

We envision an equitable, collegial, and collaborative department, such that the whole is greater than the sum of the parts. We value diversity, learn from each other, and are able to take on larger challenges by combining different areas of expertise.

In an increasingly connected academic world, we engage with our colleagues across the globe on a daily basis. However, it takes deliberate intent to build and maintain community within the School. Community is critical to the development of our graduate students, such that they can develop expertise in a variety of approaches and create their unique research niche. A collegial and collaborative school is also an important consideration in faculty recruitment and retention.

We will become an integral part of the larger GT community, playing leadership roles in research and education efforts in environmental sustainability and planetary sciences across science and engineering disciplines.

Being embedded in one of the major technological research universities in the world provides the School with unique opportunities to take advantage of new technologies and approaches as they are being developed. Although most EAS faculty participate in cross-school and cross-college collaborative research, we hope to lead more large-scale collaborative efforts in the coming decade. In particular, we hope to lead Georgia Tech-based planetary science missions, as well as programs related to Climate and Environmental Sustainability, including their impacts on Natural Hazards. We also envision EAS leading interdisciplinary degree and certificate programs. We will continue to build on existing programs, such as the Ocean Science and Engineering Ph.D. degree and the Astrobiology graduate certificate. We also envision leading interdisciplinary undergraduate programs in these areas, as well as graduate and undergraduate programs in Climate and Environmental Sustainability.

ACTIONABLE GOALS

ACADEMIC PROGRAMS

Goal 1: Align undergraduate major and minors better with needs of present and future students

We need to better understand the career aspirations of our students, and determine the skills that are needed for the jobs for which they will be competing and that will serve them over the course of their working life. At the same time, we need to accommodate the great breadth of backgrounds and interests of our students. We feel that better aligning our programs with the motivations and needs of students will help us grow the size of our undergraduate major.

Our faculty are justifiably proud of the quantitative and scientific rigor of our undergraduate program. Our students in the meteorology track are well-prepared for work in their field, and students who participated in undergraduate research and excelled in their coursework are well prepared for graduate school. Given the likelihood that graduates with strong scientific and computational skills will continue to be in high demand and find career success, we need to continue to offer and encourage this preparation to those who can benefit from it. Overall, the preparation of incoming students at Georgia Tech is extremely strong, and many can thrive with quantitative coursework. **We will explore the possibility of renaming our existing major (perhaps with some small modifications) to fully reflect that it is a Computational EAS major.** At the same time, a significant number of our students are overwhelmed by the quantitative coursework, and it is not always clear that they are benefitting from the rigor of the curriculum. This is particularly the case for many students who transfer to Georgia Tech from other state institutions (24% for class of 2020). **We will explore ways to support these students in gaining the necessary skills to succeed in the Computational EAS major.**

Students are also increasingly interested in societally relevant science, especially related to climate and the environment. These students may want additional coursework in International Affairs, Psychology, Biology, Business, the Arts, or Environmental Engineering, for example. The many requirements of our current major, prevent students from being able to take elective courses in other areas of interest. In a recent survey, our alumni expressed that they would have been better served in their careers if they had taken a broader array of courses outside of their major while at Georgia Tech. **To accommodate students with more interdisciplinary interests, we will explore creating a more flexible major with a focus on the Environment.** Streamlining the math and science requirements and reducing the number of required courses overall could attract a wider range of students and would allow students with broad interests in the intersection between science and society to take more coursework in the social sciences. A more flexible major would also enable students to transfer into our major without increasing time-to-graduation. This is especially important for EAS, as less than 25% of undergraduate geoscience majors nationwide choose the major before entering college, with the remainder transferring into the major during college, most often during the second year (AGU Status of the Geoscience Workforce, 2018).

In addition to rethinking our majors, **we will explore the possibility of creating interdisciplinary educational programs (majors, minors, certificates) in Astrobiology and Global Change**.

- *Implementation:* When new institutional academic requirements have been set, the Undergraduate Coordinator and Curriculum Committee will explore any possible changes in the EAS major(s), with the opportunity for input from faculty and students. Any changes will be made in concert with the new USG and institutional requirements that are currently under development. Any curricular changes will need to be approved by the faculty and institute. The Undergraduate Coordinator will work with disciplinary faculty in developing the interdisciplinary programs.

- *Timeline:* New major requirements will roll out in concert with the new institutional requirements (currently set for Fall 2021). The interdisciplinary programs will be developed after the new institutional requirements are in place.

- *Metrics for Success:* If we are successful, we will see increased undergraduate enrollment in the major. We will also examine the responses on exit interview questions that are aligned with the changes. We will consider new certificates and minors to be successful if they increase the enrollment of non-majors in the relevant classes.

Goal 2: Enhance career planning and development for both undergraduate and graduate students

Our undergraduate and graduate students are increasingly setting their career goals outside of traditional academic and government research careers. We will examine what we can do to better prepare our graduates for an array of different careers, and connect them with these opportunities. Not only will this benefit the students, but it will make us more attractive to prospective students and their families who can be concerned about employment prospects. For those students (both grad and undergrad) who do not wish to pursue careers in academia, we need to encourage and better connect students to internships, co-ops, workshops, etc. in their planned fields. For graduate students, we should examine whether joint degrees or coursework opportunities in engineering or policy could increase the success of Ph.D. graduates in non-academic careers. In addition, we need to ensure students have sufficient opportunities to connect with employers through career fairs, alumni visits, and interactions with governmental agency and environmental industry partners. For undergraduates who are moving on to graduate school, we will make sure that they are being appropriately advised.

- *Implementation:* Graduate and Undergraduate Coordinators will work together to develop or identify resources such as career fairs and lists of internship opportunities. They will leverage existing resources within Georgia Tech and at other institutions, and/or work with other groups both within and outside of Georgia Tech to develop online resources, and to update and improve the information on the EAS website.

- *Timeline:* Identifying some resources for internships and career and grad school advising will start immediately, but be fully developed on a 3-year time scale.

- *Metrics for Success:* We will examine the responses to student exit interview questions that are aligned with these changes and the career outcomes of our graduates using our alumni database.

Goal 3: Develop a leading role in expanding the demographic diversity of the workforce in Geosciences

We will examine how to make our undergraduate and graduate education programs attractive to students from underrepresented groups, and ensure that the programs are well structured for students from all backgrounds. Better recruitment and outreach can be part of the plan, but we also need to ensure that our program does not present any undue structural barriers to the participation and success of students from underrepresented groups. We need to listen to these students and learn about their unique challenges, interests, and career goals and adjust our program accordingly. The more flexible environment-focused undergrad major may help to attract additional students from underrepresented groups. For undergraduate and graduate students whose math background is not as strong as others, we need to develop early opportunities within the curriculum to bolster their skills and even the playing field. Some institutions are implementing summer math and computing brush-up programs for students who could benefit. Although our application to participate in the AGU Bridge Program (which matches URM students with supportive graduate programs) was not successful this year, we look forward to receiving comments about how we can better structure our program. We have taken a strong first step in voting in fall 2019 to eliminate the GRE requirement for graduate admissions; to our knowledge, we are the first School at Georgia Tech to do so. We also have embraced the importance of adding faculty from underrepresented minority groups through diverse searches and hires, and we will continue to prioritize faculty diversity.

- *Implementation:* Graduate and Undergraduate Coordinators will work to identify barriers to participation and success. The Graduate Admissions committee will explore recruiting strategies and continue to work towards participation in AGU bridge program. Undergraduate Coordinator will work with the Committee on Undergraduate Recruitment and Environment (CURE-EAS) to explore recruitment efforts focused on underrepresented groups within the State and University. The School leadership provide regular updates on program demographics to the faculty, and will actively engage faculty in conversations about these issues. Faculty will identify potential target of opportunity faculty hire(s) and school leadership will pursue them.

- *Timeline:* The identification of barriers and remedies of these structural impediments will take place as part of the revisions to the undergraduate major (Goal 1). Enhanced recruitment of students will follow the identification and remediation of structural barriers. Efforts for Opportunity hires are ongoing.
- *Metrics for Success:* Increased number of Black/African American and Hispanic/Latinx undergraduate and graduate degrees awarded and increased retention of students in these groups.

RESEARCH AND FACULTY DEVELOPMENT

Goal 1: Develop research leaders in post-tenure faculty

The School of Earth Atmospheric Sciences has a uniformly strong, research-active faculty covering a wide range of research areas. The school has consistently recruited strong junior faculty and provided them the needed support to launch successful academic careers. Many of our early career faculty have won prestigious early career awards over the past decades. However, mid-career faculty development has not received a commensurate amount of resources and attention. Only with increased attention to mid-career faculty development can EAS retain its strongest faculty and become a department of international stature, populated with research leaders performing at their full potential.

For the most part, our current faculty feel positively about being at Georgia Tech. They love being at a premier technological research university, and enjoy being part of a community of strong, research-active faculty in EAS. However, EAS has recently lost a number of mid-career faculty. The lack of support for laboratory and computing infrastructure, repair, and replacement beyond the initial start-up package limits the impact of research programs. The lack of institutional support for students and post-docs beyond the start-up period also limits the ability of faculty to build in new research directions. This encourages faculty to look for outside offers as the only way to update their research program. Many faculty members also feel limited by the lack of the needed administrative support to lead and develop large interdisciplinary proposals that involve multiple PIs and institutions. They also note the increased administrative burden associated with budgeting, travel, scheduling, and purchasing which is not accompanied by increased support positions. These resources are available to mid-career faculty in many of our competitor institutions and allow faculty to build internationally leading programs.

The majority of these supports require money that goes beyond what is standard and permissible on research grants. EAS has limited access to fundraising from foundations and the private sector, and faculty feel that they are actively discouraged by the structure of the development efforts at Georgia Tech from gaining better access to these resources. Although this issue needs to be addressed at a higher level, there are some things that we can do within EAS.

We will develop a plan to better mentor and support mid-career faculty. Co-mentoring, perhaps on a college-wide level, might be the best model for mid-career faculty. Regular research leaves are one mechanism to re-invigorate research, and should be available to all faculty and not be limited to faculty whose family situation allows them to spend a semester at a different institution, as is currently required for CoS Faculty Development Leaves. **We can also explore incentives for the preparation of multi-PI grant proposals** with the resources currently available within the school (e.g. administrative help, service and teaching assignments, etc.). **Department**

leadership will also advocate on issues that need to be systematically addressed at a higher level (allowing development opportunities, resources for research renewal of mid-career faculty, etc.).

- *Implementation:* The Associate Chair will develop a plan for the systematic mentoring and support of mid-career faculty. The Chair will advocate for resources for mid-career faculty development and support at the College and Institute level.

- *Timeline:* Developing a plan for enhanced mentoring and support of mid-career faculty will be a focus during AY 2020-21. Advocacy for addressing resources for mid-career faculty will be ongoing.

- *Metrics for Success:* More of our faculty will be become international scientific leaders in the next decade. EAS will be leading more multi-institutional research programs. Our faculty will be recognized with more mid-to-late career awards and faculty retention will be increased.

Goal 2: Integrate better into the GT community and beyond

While the funding environment in the Earth Sciences has been relatively stagnant, a concurrent shift towards opportunities for large, collaborative, interdisciplinary projects has emerged. Obtaining these grants will necessitate a shift towards a more collaborative culture extending beyond the School than was the case for the single PI funded grants of the past. Some of these opportunities are likely to focus on impacts and adaptations necessitated by global climate change. There will also be opportunities related to upcoming NASA missions across the solar system. Research in the Earth and Atmospheric Sciences, as in many fields, is being driven by technological advances including robotics and remote sensing, ever increasing data streams, and techniques to handle "big data", high performance computing, and machine learning. Another development includes the full incorporation of biology and microbiology into our understanding of the Earth System. **All of these trends point to the importance of better integrating the activities of EAS into the fabric of the institute as a whole.**

Coupled with these external research trends is a strong interest on the part of Georgia Tech to tackle important global challenges, many of which focus on environmental sustainability. Research in EAS must be more central to any university-wide initiatives in this direction. Not only do we have the expertise to understand the key natural systems (atmosphere, hydrosphere, and geosphere), much of the current research effort in the school is keenly focused on the aspects of the Earth system that impact humans and ecosystems. This research ranges from tsunami prediction to earthquake risk, from the impact of global climate change on ocean chemistry and biology to the ocean controls on atmospheric CO_2, from projections of ice sheet melt to the impacts of sea-level rise on the Georgia coast, from understanding the role of climate change on precipitation patterns and intensity to the impact of wildfires on air-quality, and from the impact of environmental pollution on ecosystems to the remediation of impacted environments. We need to build visibility for these established research thrusts, and to better connect with other centers of sustainability research across the institute.

Some of this integrative activity is already taking place. In recent years, EAS faculty have had a major role in the establishment of the Ocean Science and Engineering (OSE) Graduate Program and the Astrobiology graduate certificate program. The former is intended to spur new research collaborations and the latter to solidify existing collaborations. EAS faculty have also been integral in starting the new Global Change Program, but more should be done to integrate EAS activities into this and other efforts surrounding sustainability at Georgia Tech. Better communication is needed between the various sustainability related programs at Georgia Tech and the leadership and relevant faculty within EAS if the School is to build effective research and educational partnerships. One suggestion was to have a designated committee to facilitate regular communication among leaders of environmental sustainability educational and research initiatives, although this would have to happen at a higher level than EAS.

Another piece of the solution is to raise awareness of the strengths of our School among faculty and students across Georgia Tech, and that it has expertise that may be relevant for them and their research and educational programs. Publicity tends to be focused on a few areas, and EAS needs to do a better job ensuring that a variety of interesting stories get out. One possibility would be that the Chair, a publicity committee, or a staff member regularly meet with the College of Science Communications Director to pitch story ideas. Enhanced use of social media may also be helpful. Additional outreach to Georgia Tech students (through Earth Day programming, for example) may also raise our visibility on campus.

- *Implementation:* School Leadership will meet regularly with directors of campus efforts in Environmental Sustainability that overlap with the research and educational programs in EAS. A mechanism will be set up to better communicate the activities in EAS to the rest of campus.
- *Timeline:* These activities can begin immediately, although it may take some time for them to bear fruit.
- *Metrics for Success:* Students from other educational programs are taking more coursework in EAS. More faculty are participating in research collaborations outside of EAS, and EAS faculty are playing a role in new Georgia Tech programs related to Environmental Sustainability.

Goal 3: Strengthen and enlarge our faculty in high priority research directions

Over the last 15 years, the faculty hiring strategy in EAS has typically been to cast a broad net, and to focus on hiring the strongest candidates that can both contribute to and benefit from the community and resources here at Georgia Tech. Criteria for assessing this strength include traditional indicators of scholarly excellence (research output, research plans) as well as strong potential for teaching and mentoring students of all backgrounds. Attention has also been given to ensuring demographic diversity in the candidates and hires over time. As a whole, we find the “wide net” vs. “replacement hire” approach to faculty recruiting helps keep an exciting research mix. We will continue to cast a wide net, especially when considering targets of opportunity.

Once the existing empty lines are filled, there is a sense that our School has the right number of faculty to sustain vibrant research and educational programs. However, it was also felt that strategic growth could be beneficial, especially in response to campus initiatives and priorities, emerging funding opportunities, or in response to increased student enrollment. In the Faculty Hiring Plan below, we make the case that additional strategic hires in three areas of existing strength could propel Georgia Tech into national leadership in these fields.

- *Implementation:* School leadership will request authorizations to search in the strategic areas.
- *Timeline:* Replacement of recently vacated faculty lines will take place in AY2020-2021. Searches for target of opportunity hires, in particular those that will increase the demographic diversity of the School, will be ongoing. Any additional expansion lines would be contingent on identification of resources.
- *Metrics for Success:* Successfully recruit faculty in targeted areas.

BUILDING STAFF, STUDENT AND FACULTY COMMUNITY

Goal: Build collaboration and community within EAS

Faculty and graduate students, for the most part, enjoy and respect their colleagues greatly. We pride ourselves on our relatively welcoming and inclusive environment. However, both the faculty and graduate students find that the amount of scientific interaction is less than ideal. Many bemoan the lack of participation in weekly seminars and receptions, and some disciplinary groups have fostered less community than others.

We will investigate strategies to improve seminar attendance, to increase the number of department-wide social events, and to reduce the isolation of students within their research group. Examples could include involving students in organizing the seminar series, ensuring that all students attend a weekly disciplinary seminar, and ensuring that graduate student faculty advisory committees meet regularly. Staff also feel they would value the opportunity to learn more about the work of the department. Possible strategies could include short talks at weekly staff meetings, encouraging staff to attend talks given on campus by EAS faculty pitched for a general audience (Frontiers in Science Lecture, etc.), or a once-a-semester lecture within EAS pitched for a general audience, including undergraduate students and staff. While undergraduate student community has improved considerably in recent years, with the addition of a study room, student club, and monthly student-of the-month awards, more frequent communication with undergraduate students, perhaps in the form of a regular newsletter, may be warranted.

- *Implementation:* The graduate coordinator and graduate committee will propose changes in graduate program structure and procedures to ensure that students are not isolated. Department leadership will ensure that sufficient department-wide social events are organized and provide opportunities for staff to learn about EAS research. The seminar organizing committee will implement strategies to encourage higher participation.
- *Timeline:* Efforts will begin immediately, but it may take time to identify the most effective strategies.
- *Metrics for Success:* Better attendance at departmental seminars and receptions. More regular meeting of graduate student advisory committees. We will also examine the responses to questions on the graduate student exit interview that are aligned with the changes.

SUMMARY

Over the next decade the school of Earth and Atmospheric Sciences will be well primed to make significant contributions to our understanding of the Earth and other planets in our solar system. The opportunities in Earth and planetary sciences are expanding, driven by an increase in planetary exploration and the increased importance of understanding and mitigating the planetary footprint of human activities here on Earth. At Georgia Tech, we are well positioned to fully capitalize on the technologic advances that are driving progress and discoveries in these areas. Optimizing our research impact will require that we provide the necessary supports to mid-career faculty in order to encourage scientific leadership, better integrate EAS research activities with the institution as a whole, and strengthen and enlarge the faculty in a few high priority research areas.

The ever-increasing importance of the interactions between human populations and the Earth and its environment will continue to drive the demand for a diverse pool of trained professionals with a solid understanding of quantitative and basic sciences, good communication skills, and a broad perspective on environmentally related societal issues. We can play a crucial role in expanding the demographic diversity of the geoscience workforce through more effective recruitment of students from under-represented minority groups, and identifying and removing barriers to success in our degree programs. The requirements for our undergraduate major and minors must be better aligned with both the preparation and future careers of our students, and we also need to ensure that they can better connect to career opportunities outside of research and academia. An increased focus on scientific community within the School will better prepare our graduate students to become leaders of the next generation of Earth and Atmospheric Scientists.

While some of these goals can be addressed with concrete action from within the School of Earth and Atmospheric Sciences, some will require, or benefit from, coordination with other schools and leadership within the College of Sciences and more broadly across the institute.

APPENDIX:5-10 YEAR HIRING PLAN

LIFE BEYOND EARTH

Planetary science and astrobiology are areas of strength in EAS. Four current and soon-to-arrive faculty members (Rivera-Hernandez, Schmidt, Simon, Wray) conduct modeling, laboratory, and field research in planetary analog environments and analyze spacecraft data as members of NASA and ESA planetary science mission teams. Three current faculty members (Glass, Reinhard, Tang) use the tools of geochemistry and microbiology to understand the early evolution of life and the environment on this planet. The expertise within EAS is complemented by that of faculty in Biological Sciences, Physics, Chemistry and Biochemistry, and Aerospace Engineering who are working on similar issues. Space missions make the discoveries and set the research priorities driving much of planetary science, and they also receive the vast majority of federal funds within the field. Mission leadership is therefore an understandable aspiration of many practitioners, including current GT faculty.

Only a handful of universities have been selected to lead space missions. Georgia Tech is well positioned thanks to its robust engineering programs, comparable to those of MIT (2011 GRAIL lunar mission, \$496M), Caltech (2001 Genesis solar wind probe, \$264M), UCLA (2007 Dawn asteroid mission, \$446M), and the University of Maryland (2005 Deep Impact comet mission, \$330M). But as the unexplored “low-hanging scientific fruits” of the inner solar system dwindle in number, the resource requirements for novel planetary science missions tend to grow over time. Within the past decade, only two universities have won comparably large planetary mission contracts: Arizona State University (2022 Psyche asteroid mission, \$900M+) and the University of Arizona (2007 Phoenix Mars mission, \$386M; 2016 OSIRIS-REx asteroid mission, \$800M). Most recently, when NASA announced on February 13, 2020 the four finalists for its next (\$450M) planetary mission, only one was led by a university PI: Io Volcano Observer, again from the University of Arizona.

Although a variety of factors contributes to any mission’s selection, the University of Arizona has one obvious advantage: the world’s largest department of Planetary Sciences, boasting 39 faculty. ASU includes fewer, yet over a dozen, planet-focused faculty. At both institutions, multiple scientists in the same department lead credible (sometimes competing) mission proposals, drawing experienced Deputy PIs and Co-Investigators from their local faculty colleagues. Both institutions also succeeded first at winning instrument contracts before they led entire missions, such as the 2006 HiRISE Mars camera (\$31M, University of Arizona) and ASU’s half-dozen thermal emission spectrometers launched since 1996 on missions to Mars, the asteroid belt, and soon to Europa.

To approach the critical mass enjoyed by these mission-capable institutions, we would need multiple faculty hires, likely spread across schools. **In the near term, EAS can bolster its position by hiring faculty with demonstrated expertise and interest in developing instrumentation for planetary science missions.** To best leverage our existing strengths, new faculty would ideally share an interest in astrobiology, i.e. in the characterization of habitable environments, prebiotic chemistry, and ultimately evidence for life beyond Earth. This subject area has already involved a number of faculty from EAS and from several other GT schools that host NASA and NSF-funded centers addressing these questions. With additional potential ties to other areas of EAS (e.g., glaciology, oceanography, and geophysics), planetary astrobiology is an area in which further growth of our faculty would be widely beneficial, while sowing the seeds for eventual leadership in space mission design and operations.

FLUID EARTH

While geophysical fluid dynamics provides a foundation for the study of the atmosphere, ocean, and near-space environments, the role of fluid flow in solid Earth processes is equally important. The multi-phase fluid flows of geological systems present a modelling challenge, but advances are being made particularly in the areas of the physics of interfaces, granular materials, and high-performance computing. Fluids play a critical role in the chemical and structural evolution of the crust and mantle, the evolution of surface landscapes, the generation of earthquake activity, and the sustainable production of energy. In addition, fluid flows control the exchange of volatile elements such as carbon between the surface and subsurface through time. These exchanges, in turn, impact atmospheric composition over long time scales. Understanding these processes is thus critical for establishing atmospheric conditions and habitability early in Earth history and on other planetary bodies.

The work of a number of faculty encompasses fluid flow in the Earth as it impacts tectonic processes, earthquake activity, and landscape evolution (Lang, Naif, Newman, Peng), early atmospheres (Reinhard) and meltwater/glacier physics (Chu, Robel)**.** The addition of a faculty member with specific expertise in geofluid modeling could enhance research efforts in tectonic geomorphology (Lang), geodetic modeling (Newman), electromagnetic (Naif) and seismic (Peng, Herrmann) imaging of the Earth. This new faculty member would allow for new collaborations for competitive tectonics and hazards-focused proposals to NSF in one of several large interdisciplinary programs such as Frontier Research in Earth Science (FRES) and Prediction of and Resilience against Extreme Events (PREEVENTS), as well as DOE’s new initiative in renewable energies (e.g., geothermal). The faculty member could also potentially play a key role in advancing the School's research goals in astrobiology and planetary science, in particular as a participant in collaborative proposals to the newly formed NASA ICAR program. This faculty member could also link to research in geotechnical characterization and seismic and coastal hazards in Civil and Environmental Engineering, as well as research in fluid mechanics in Material Sciences and Engineering and Mechanical Engineering.

CLIMATE: SCIENCE TO SOLUTIONS

Climate change represents the defining challenge of the 21st century. The geosciences have played a key role in identifying the drivers as well as the impacts of climate change, and are poised to play a key role in identifying scalable solutions to the problem. On the one hand, ambitious greenhouse gas mitigation efforts require a better understanding of the sources and sinks of greenhouse gases, including CO_2, CH_4, and other radiatively active gases of anthropogenic origin. On the other hand, even under the most ambitious mitigation efforts, the impacts of climate change will continue to threaten communities, and the ecosystems they depend on, for decades to come. The development of climate solutions will lean on research in every discipline currently represented in EAS, as well as many disciplines across the College of Science, and the entire Institute.

Climate Solutions fall into three main categories, all of which require Geoscience expertise in areas of current strength in EAS and in areas that would need to be strengthened through new hires:

Mitigation is the reduction of net greenhouse gas emissions either through decreases in emissions or increases in sinks. Developing effective mitigation strategies requires a better understanding of the environmental sources and sinks of greenhouse gases. Understanding controls on the sinks of CO_2 and CH_4 requires atmospheric observations and modeling, better constraints on terrestrial carbon budgets (soils, forests, permafrost, wildfires/disturbance), better constraints on marine carbon budgets (the Southern Ocean, upwelling zones, coastal wetlands), and understanding the fate and stability of methane hydrates. We currently have good expertise related to marine carbon cycling (Bracco, Cobb, Glass, Ingall, Ito, Reinhard, Taillefert), but limited activity (Kostka, joint with Biology) focused on land sources and sinks. Our growing expertise on methane hydrates (Glass, Naif), would be bolstered by more expertise in Geofluids (see above). Additional expertise in longer-lived greenhouse gasses, such as methane or nitrous oxide, would strengthen existing research in atmospheric chemistry and marine/terrestrial greenhouse cycling.

Geoengineering is the deployment of nature-based or technology-based interventions to alter Earth's radiative balance and/or accelerate the removal of CO_2 from the atmosphere. Solar Radiation Management via sulfate or the manipulation of cloud radiative properties requires an understanding of atmospheric aerosols (a current strength in EAS). Land afforestation and reforestation requires expertise in land ecosystems and soil. Accelerated weathering approaches and oceanic and geological sequestration of anthropogenic CO_2 require expertise in geochemistry, geofluids, and ocean biogeochemistry.

Adaptation is the creation of strategies to protect communities and ecosystems from ongoing and future climate impacts. A prerequisite to effective adaptation is to characterize and predict these impacts. The changing frequency and intensity of extreme events in weather and climate (Bracco, Cobb, Deng, di Lorenzo, He) is still not well understood, and urban climate is an area of particular interest. Changes in water availability for natural and agricultural systems are also likely to have a large impact. Sea level rise will result from melting ice (Chu, Robel), but the rate of sea-level rise and the impact on sedimentary coastlines such as Georgia's are not well constrained. Ocean acidification and ocean deoxygenation (Ito) are also potentially important impacts that need to be better understood. A warming climate is also influencing terrestrial ecology, fire frequency and air quality, and some geoengineering solutions involve the manipulation of atmospheric aerosols (McGuire, Kostka, Huey, Kaiser, Liu, Ng, Sokolik, Wang, Weber).

While we can't do all of the geoscience related to climate solutions here in EAS, we already have some expertise in many of the areas described above. We would focus on building expertise in areas that can link to the engineering expertise in other schools. The scope of each solution is much larger than EAS, or even the College of Sciences, and in most cases extends to research in all other Colleges, likely attracting joint appointments and possibly enabling the creation of a "Climate Solutions" cluster hire with appointments across all of Georgia Tech. By focusing on near-term opportunities for faculty hires in science to support Climate Solutions, EAS can leverage its strong ties to two cross-college programs, the Ocean Science and Engineering (OSE) Program and the Global Change Program (GCP).